A VERSATILE SYSTEM FOR INTERFACING SUBJECT TO TASK IN EEG ANALYSIS WITH BIOFEEDBACK

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NAVAL POSTGRADUATE SCHOOL
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THESIS

A Versatile System for Interfacing
Subject to Task
in EEG Analysis with Biofeedback

by

Dennis Cruce Marvel

December 1975

Thesis Advisor: George Marmont

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A Versatile System for Interfacing Subject to Task in EEG Analysis with Biofeedback

by

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Lieutenant, United States Navy
B.S.E.E., University of Mississippi, 1967

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I. INTRODUCTION

The Bioengineering Laboratory of the Electrical Engineering Department of the Naval Postgraduate School has long had an interest in the mental activity of man and specifically in Naval men in the hopes that it could contribute to their understanding and upgrade their performance of systems or equipment. Over the past few years, there has been increased emphasis upon the learning process and an upgrading of the methods of EEG data collection and analysis.

Under the direction of Dr. George Marmont, a group of thesis students have each made his own contribution toward the understanding of the mental process and its relationship with every day life. The implementation of the tasking subsystem described in this thesis is the author's specific contribution with the hope that it will further this understanding.

II. BACKGROUND

A. THE ELECTROENCEPHALOGRAM

In the 100 years since Richard Caton's [Ref. 1] first report of the recordings of electrical activity from the brain of animals, there have been slow but significant advances in the study of the electroencephalogram (EEG). However, the scientific community still does not know precisely where and how these continuous oscillating electrical waveforms of the cerebral cortex are generated or how they are regulated. It is generally believed that brain waves are the summative signal created by propagated action potentials and postsynaptic potentials of many neurons within the brain and brain stem.

The next major contribution was by Hans Berger [Ref. 1], when he published the first studies of the human EEG in 1929. Using the string galvonometer, with little or no amplification, Berger was able to detect two of the major components of the EEG which he called the alpha and bata waves. The alpha wave is about 10 Hertz and ranges in frequency from 8 to 12 Hertz in different individuals. The bata wave is higher in frequency and, depending upon source, ranges from 13 to 50 Hertz. Because of the increased prominence of the alpha and reduced potential of bata waves, Berger's studies of attention, perception, problem solving and thinking dealt primarily with the alpha wave. Over the next 10 years, he

concluded that the blocking of the alpha wave was related to increased mental activity. It is now generally accepted that alpha is associated with a relaxed state and can be generated by most people when their eyes are closed.

Berger's published results and the invention of the "push-pull" amplifier (Mathews 1934), which reduced common mode interference, gave rise to increased interest in the scientific community. This led to the discovery, by Walters in 1937, of slow waves with large magnitude at a frequency of 2 or 3 per second called delta waves. It is now more generally accepted that delta waves range from .5 to 6 Hertz and occur during sleep in the healthy adult.

In 1943, Walters also introduced a fourth characteristic of the EEG. He termed the high amplitude, low frequency components of 5 to 7 Hertz as theta rhythms or theta waves and postulated that they scan for pleasure. They have been associated with creative hallucinations and anxiety [Ref. 2] by some individuals; but these viewpoints should be taken with skepticism.

The above four frequency bands are considered the basic components of the EEG. Others, postulated by different individuals, and their characteristics [Ref. 1] are:

1.	Gamma	30 - 50 Hz.
2.	Kappa	8 - 12 Hz.
3.	Lambda	pos-neg spike
4.	K-Complex	positive sharp wave
5.	Sleep spindles	12 - 14

Since 1950, techniques, technology, and sophistication have improved significantly. With the electronic advances

that have been made, researchers now are able to expand their ideas and curiosity. The most recent advance has been the application of special purpose computers and data processing techniques to the collection and interpretation of the EEG. The major directions of current EEG study are: (1) animal studies to determine the source and nature of the EEG; (2) human studies to determine the normal function of the EEG and (3) human studies to determine their correlation with abnormal behavior.

Of the above studies, the last appears to have been the most successful to date, for it is far easier to take persons with a known disorder and statistically compare their EEG to those considered normal. However, there have been cases where persons with severe brain defects, such as Parkinsonism, congenital cerebral palsy, and mental retardation, have had quite normal EEGs. On the other hand, a normal EEG tracing does not exclude the possibility of an organic brain disorder. The results of these studies have led to the wide use of EEG machines (Electroencephalographs) in clinical neurological and psychiatric medicine. These commercially available electroencephalographs permit simultaneous recording from 8 to 16 or more positions on the head.

B. BIOFEEDBACK

Feedback is a fundamental engineering concept and has been important in engineering from the earliest times. However, Bell Telephone Laboratories is credited with the

early work on feedback theory, as it is known today, in the 1920's. Their work was motivated by the advent of trans-continental telephone lines, which used a large number of repeater amplifiers. In order to keep the system characteristics constant as these amplifiers deteriorated with age, Bell Lab turned to the use of large amounts of feedback within and around the amplifiers. This use of feedback was to obtain an increased reliability to preclude the expense and difficulty of pulling up cable from the ocean for repairs and adjustments to the amplifiers. Thus, feedback is a useful viewpoint when a feedback path is purposefully inserted to achieve some desired characteristic or result.

Illustrations of this basic principal are found in every-day life. For example, Fig. 1 depicts a human feedback system. In this simplified model, a pencil is observed laying

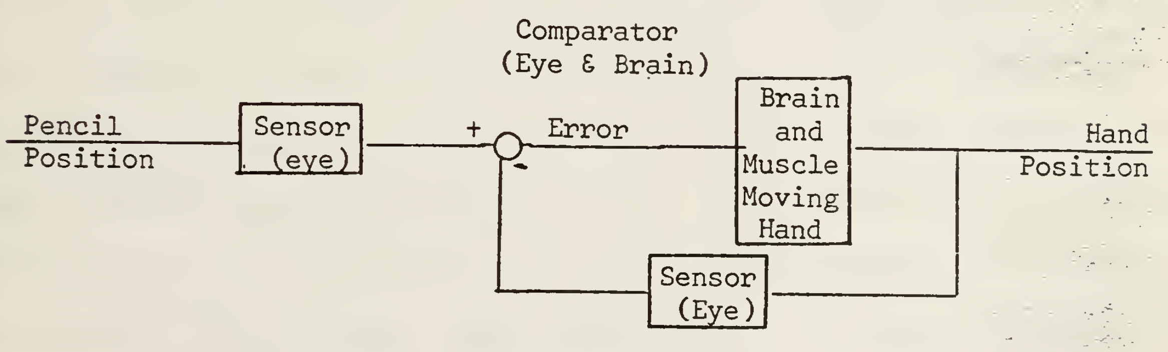


Fig. 1 A Human Feedback System

on a desk. If one wishes to pick it up, he must make a motion with his hand. At each stage of the motion, the eye and brain are making a comparison between the pencil position and hand location. This process is repeated until the desired

result is accomplished, that of picking up the pencil. The fact that one can pick up a pencil with his eyes closed shows that this is a simple model and doesn't include all inputs, for we can sense hand motion and compare this with pencil position.

When this fundamental principal is applied to a subject and the function fed back to that subject is biological information, it is termed biofeedback. The essence of past experimental biofeedback has been to give the person information about changes in some particular function, such as cortical alpha activity, heart rate, blood pressure, or body temperature, and to reward him for responses of a given amplitude or direction. If the function fed back is obtained from the brain's electrical activity, then it is EEG feedback. If the source is from muscle action potentials, then it is termed Electromyographic (EMG) feedback. Regardless of source, the characteristics of good biofeedback are: (1) parameter selected for feedback must be the proper one which reinforces the desired modification in output, (2) presented in a timely fashion, i.e. immediately, in order to reinforce the desired response and not some random response, (3) capable of detecting and presenting small changes in the function selected and, (4) should not distract the subject from his task.

Given that we have the necessary characteristics of biofeedback, it still remains to be shown that biofeedback does have a likelihood of success in achieving the desired results in human studies. That positive success can be achieved is

strongly indicated by published results [Ref. 2] of other biofeedback experiments which show that muscle and nervous systems that are normally automatic in function are actually controllable with training and practice. Self control of bodily functions has been investigated with increasing regularity over the past two decades.

Shapiro et al., [Ref. 3] have shown that systolic blood pressure can be lowered by feeding back a continuous reading to the subject and rewarding him when the reading remains down for a period of time. Shapiro's methods were applied to patients with essential hypertension at the Boston City Hospital with positive results in five of the seven cases.

Hardych and Petrinovich [Ref. 4] have shown that biofeedback can be used in the learning process. While teaching speed reading, they used EMG feedback from the vocal cords to determine if the subjects were subvocalizing. Students that were subvocalizing, were able to stop in one training session with significant increase in reading speed.

Budzynske et al., [Ref. 5], using EMG electrodes over the frontalis muscle and a high pitched tone as the feedback device, have been able to reduce tension and tension headaches in their subjects. Other experiments have demonstrated control via feedback over heart rate, alpha, beta and theta rhythms, skin temperature, and salivation. Here, as in EEG research, the major focus of the scientific world has been on phychosomatic disorders and in the possibility of using biofeedback in understanding and modifying psychosomatic symptoms.

C. NAVAL POSTGRADUATE SCHOOL RESEARCH PROGRAM

As indicated in the preceding sections, the majority of past researchers of the EEG and biofeedback studies has been directed toward the disorders of man. However, some experimental studies of perception and attention and the possible application of biofeedback training to processes germane to education have been conducted. Lindsay, et al., [Ref. 1] have shown that the average evoked potentials recorded from the right occipital cortex were significantly larger in alert subjects. Kimmel, et al., [Ref. 6] have found that if retarded children are rewarded with candy for producing galvanic skin orienting responses to stimuli of different visual forms, their performance on a later form-board task is improved. Mulholland [Ref. 7] has suggested similar applications through EEG training in the control of visual display.

Here at the Naval Postgraduate School increased emphasis has been placed on applying EEG technology and biofeedback training to healthy individuals in order to increase their vigilance while decreasing training time. The specific objectives of the program were to apply modern signal processing techniques to analysis of the EEG with the following expected results:

(1) New insight into the meaning of the EEG as an expression of brain function

(2) New knowledge that would lead to the determination of mental state, such as incipient fatigue

(3) New discoveries that, through biofeedback, could be used in the reinforcement of an individual engaged in a demanding mental task.

These objectives presuppose that the brain and its resultant EEG has a preferred or most efficient way of processing information supplied by its receptors and that a student or "operator" can achieve this most effective state through the use of biofeedback. Each individual is an "operator" at some time in his daily life, be it the business man driving his car or the radar operator aboard ships at sea. If some display illumination such as the speedometer of a car or the radar illumination itself, could be color keyed to the individual's EEG, then each subject would know immediately if they were operating at peak efficiency or at a reduced capacity.

III. SYSTEM DESCRIPTION

Experimental studies are often more demanding than clinical studies since specific information is sought and usually in support of some particular hypothesis. Every system designed in support of these studies must be exact in its function, as rigid controls are required to limit the observed data to the specific stimulas condition being studied. Even so, the system must be flexible should experimental results indicate a need for change. Such a system is block diagrammed in Fig. 2.

This overall system can be broken into three parts: (1) the data collection and analysis subsystem, (2) the tasking subsystem and (3) the biofeedback subsystem. Each of these subsystems were developed separately but joined in one common purpose, that of accomplishing the objectives of the NPS bioengineering research team.

A. DATA COLLECTION AND ANALYSIS SUBSYSTEM

In this system the subject under test was placed in a grounded screen room that eliminated RF interference present in the area. He was fitted with a specially designed electrode helmet [Ref. 8] that reduced the possibility of electrode movement and eliminated varying resistances, both of which lead to varying voltage measurements and inconsistent EEGs. The first degree of flexibility in the system was also provided by this helmet. Its eighteen slotted disks, each with

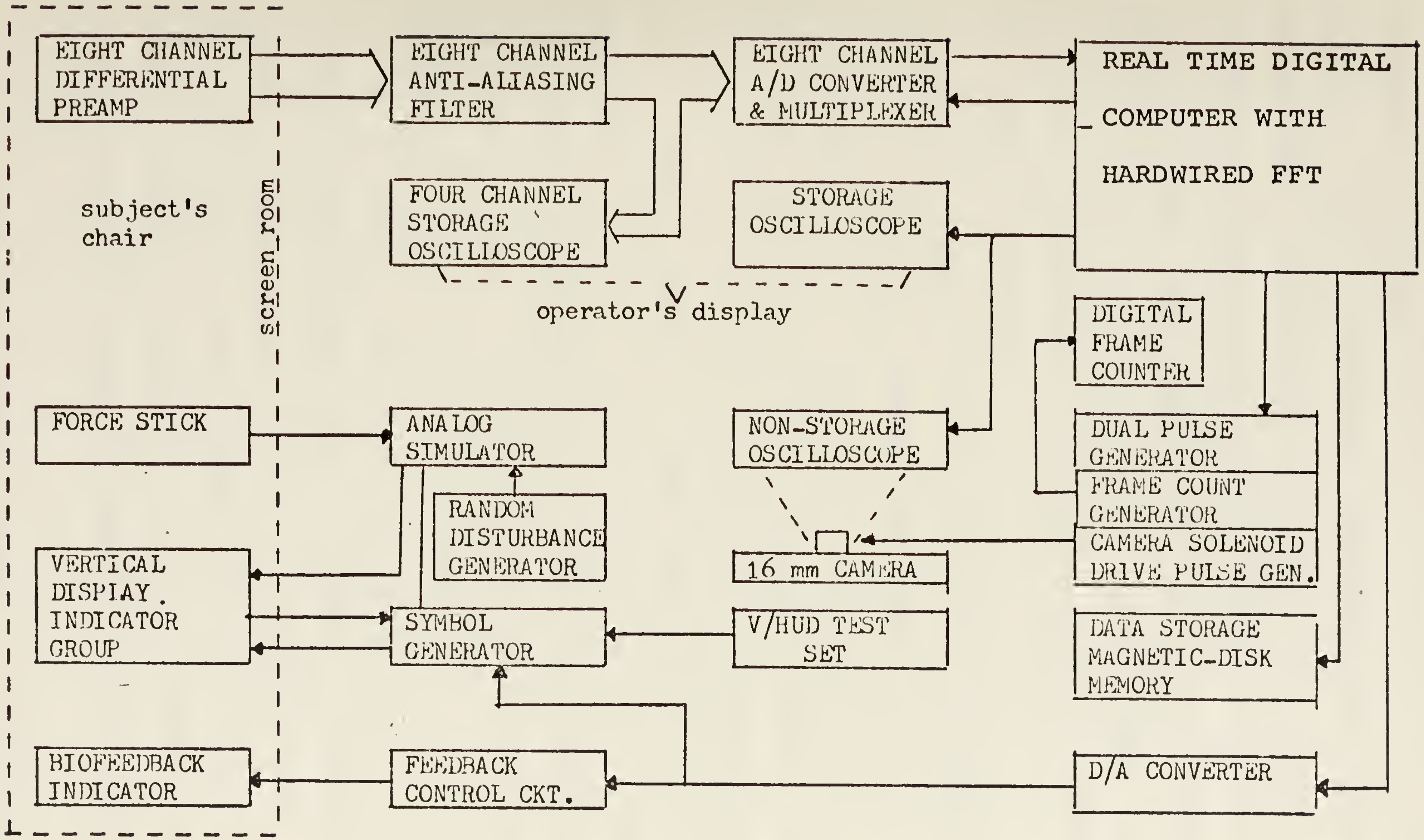


Figure 2. Block diagram of experimental setup.

four electrode positions, are rotatable and provide electrode placement to any position of the head while its rigid structure permitted exact placement of electrodes with different individuals. In addition, its light weight with no electrode discomfort allowed subject participation of up to four hours in one session. Considering the time that it previously took to prepare an individual plus the short sessions necessitated by subject discomfort, this alone would be a benefit to any EEG research program.

The EEG signals from the electrodes are then passed to eight wide-band differential amplifiers in order to reduce common mode interference while providing the gain necessary for the observation of these low level signals. These particular amplifiers have a common mode rejection ratio (CMRR) greater than 80 db and a signal gain of 4,000 with a low frequency cut off of .1 Hz. Another degree of versatility is provided by these amplifiers in that they allow selection of bipolar, unipolar and averaging methods of EEG detection, methods necessary to basic research.

In a system involving digital processing it is necessary to have anti-aliasing filters in order to suppress all frequencies greater than one-half the sampling rate. This is in accordance with the Nyquist criterion for sampled signals. These particular filters are four-pole Butterworth with a selectable high frequence cutoff of up to 1,600 Hz and a gain of 2.5.

Why such a high cutoff frequency? As stated previously, the prominence of 10 Hz waves and the low amplitude of bata

in the EEG, plus interference caused by 60 Hz power, has led almost all investigators to look below 50 Hertz. With the use of the screen room, short electrode leads, the high CMRR and high gain amplifiers, the research team did not experience these problems. Therefore, a higher frequency cutoff to expand the areas of research beyond that previously considered pertinent by other individuals.

To convert the analog EEG to digital data for signal processing the system used an 8 channel prototype of Time Data 1923 Series Analog Conditioning Elements that sample the incoming data at a programmable rate. These units are capable of direct memory access through one of two buffer registers. When a buffer is filled, its contents are automatically made available for processing by the digital processor. As the data is being processed, the other buffer is being filled with incoming data; therefore, if the processor completes its calculations and output cycles before the second buffer is full, all analysis will have been in real time.

The strength of the data collection and analysis subsystem is a Digital Equipment Corporation PDP 11/40 computer and a Time Data hardwired Fast Fourier Transform (FFT) processor. Digital processing of EEG information has been accomplished in the past but most of it in the off line condition with accompanying unavoidable delays. This versatile machine is capable of processing eight channels of EEG information on a real time basis, which is an absolute necessity if biofeedback is to be meaningful to the subject. In

addition, it has the capability for storing the entire EEG in digital form for the minute and thorough examinations necessary in research programs. It also contains two of the operator's displays; they are, (1) a four-channel storage oscilloscope, which monitors the analog EEG input and (2) a storage oscilloscope for display of the processed EEG. This particular oscilloscope is programmable for the display of up to eight channels.

Some of the advantages this system offers are:

(1) avoidance of the long time delay between performance of an experiment and availability of processed results

(2) the flexibility to use dynamic experimental techniques, i.e., to modify an experiment based on the results of that experiment

(3) assurance that all systems are performing correctly and that time is not wasted on collecting erroneous data.

B. TASKING SUBSYSTEM

In experimental studies involving attention, it is necessary to provide the subject with a mental task, observe the EEG, and correlate the two. In addition, it is necessary to process a period of comparative rest to provide a reference or control with which to compare the EEG taken during mental activity. If the subject's attention should wane during the mental task, then it would appear as if there were no correlation between the EEG and attention; therefore, a good presentation of the problem to subject is imperative. The characteristics of such a presentation are:

(1) should be interesting enough to the subject to make him want to participate in the program

(2) must be of sufficient difficulty to keep subject's interest and avoid loss of attention

(3) an unambiguous solution must be attainable, otherwise the subject will become bored and quit trying

(4) the results of the task should be capable of being graded on a comparative rating scale.

It has been determined that an effective means of presentation with these characteristics could be achieved through the use of a simulated pilot setup [Ref. 9].

Considering the fascination that man has had with flight, this would indeed offer all the characteristics. In addition to providing a task to subject for experimental EEG research, such a system, with a veteran pilot at the controls, could offer more insight into the man-machine interface problem with the possible improvement of crew stations.

With the increased complexity of modern high performance aircraft and the increased size of the jumbo jet, system instrumentation and controls of these vehicles has made the environment surrounding the pilot unbearable. He must constantly scan a large number of gages and indicator lights in order to know the status of his platform while remaining conscious of the external environment. In an attempt to increase the information flow rate to the pilot, modern aircraft designers have turned to the heads-up display (HUD).

The HUD is a system that interfaces with aircraft systems and enables the pilot to navigate and perform tactile maneuvers without diverting his attention to periodically scan the various panel instruments.

The actual device incorporated into this simulated flight tasking system is a Navy Model F-111B Aircraft Vertical Display Indicator Group (VDIG), [Ref. 10] manufactured by Kaiser Aerospace and Electronics Corporation. This system is of a comparatively advanced design with multiple display modes and two display devices. These two displays, designated the vertical or Direct View Indicator (DVI) and the Projection Indicator (PI), consist of symbols which are synthetically generated within the VDIG, but which move about the displays in response to the output from aircraft systems. The DVI is a television-type display located in the aircraft instrument panel and is primarily intended for use during instrument flying conditions. The Projection Indicator is actually a heads-up display and is an optical projection which is superimposed on the pilot's field of view directly ahead of the aircraft. In addition, to the multiple modes of simulated flight tasking, this versatile machine has an external video mode which lends itself to other tasking situations.

A complete listing of the symbols generated by the VDIG and the electrical characteristics of their control signals are found in Tables 1 and 2 respectively, of Ref. 10. Figure 3 shows the symbol configuration used in this flight tasking system and their function is indicated in Table 1. To control

these symbols, an analog aircraft simulator was built which approximates the dynamic characteristics of an F4-type aircraft flying at .9 Mach at sea level. This analog simulator offers increased flexibility in that its feedback coefficients can be changed such that the system can represent a variety of aircraft types.

The pilot's inputs to this simulator are by the same side-arm force stick controller, with modification, used in Ref. 11. In that study it was found that the side-arm force stick had the lowest average effective time delay in tasking experiments and that its average performance was significantly better than any of the other three controllers studied.

To increase the difficulty for a subject under simulated flight, pseudo-random signals are generated as inputs to the analog simulator circuit. This offers more flexibility to the system in that the time between random inputs is variable via either internally or externally generated clock pulses. In addition, each random input's amplitude is variable which increases the displacement of the VDIG symbols, thereby further increasing the difficulty of the pilot's task.

The V/HUD test set indicated in Fig. 2 is an older U.S. Air Force model, Mod 16, Part # 10551-9TFQ reengineered to provide power and mode switching capability for the VDIG. This unit also supplies the symbology on/off switching for many of the VDIG symbols. This adds flexibility in that the subject is instructed to let the research team know if he has lost particular symbols during a run. This is an additional check upon his attentiveness.

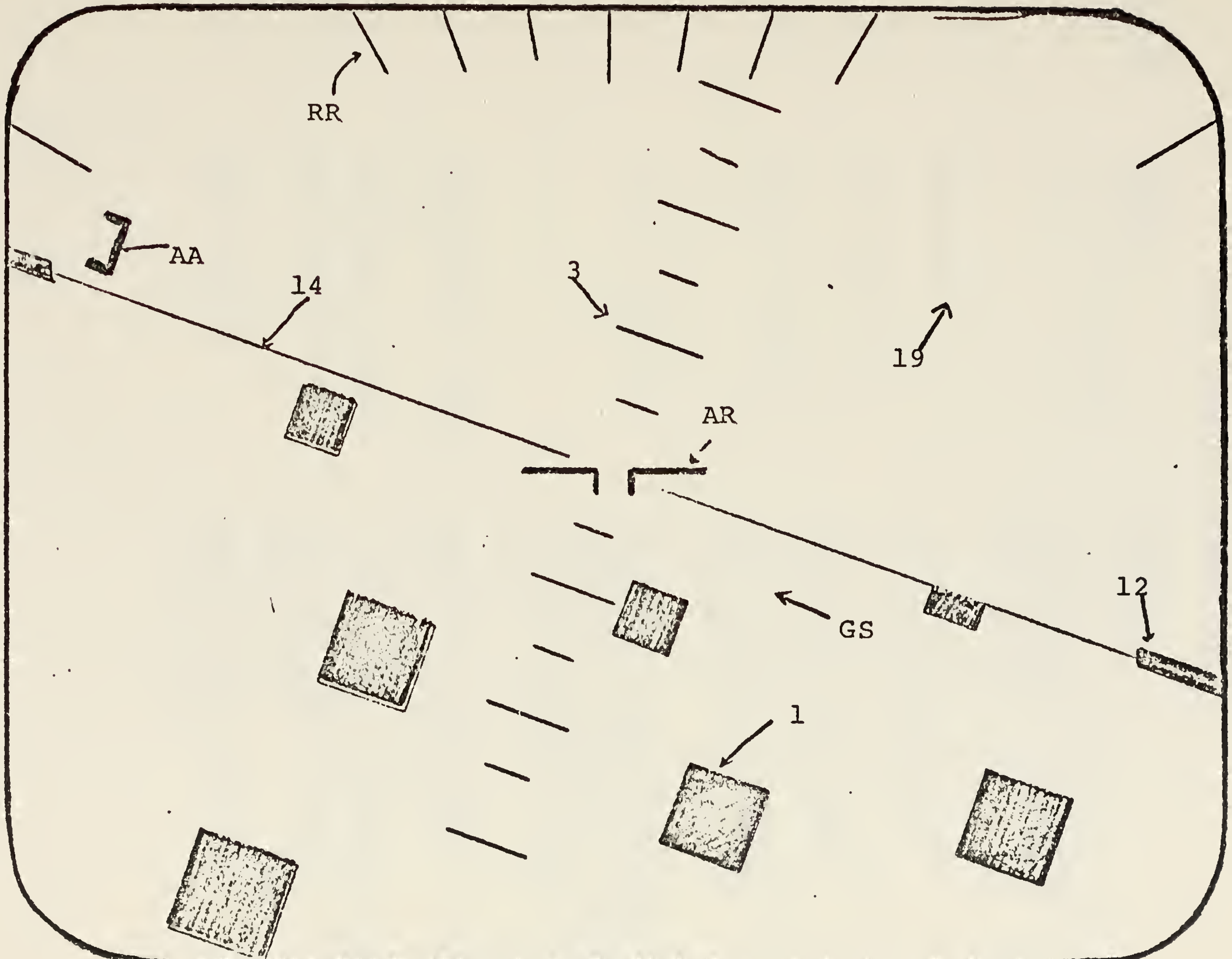


Figure 3. VDIG Symbol configuration.

Table 1

DVI Symbol Nomenclature

Number	Symbol	Function
AA	Angle of Attack	Normally to indicate desired pitch angle - in tasking system it is used as a feed-back device
AR	Aircraft	Permanently fixed symbol represents aircraft
RR.	Roll Reference	Permanently fixed symbol indicates roll angle
GS.	Ground Shading	Gray background below hor-izon, indicates ground texture
1	Ground texture	Simulate quasi-random ground texture - provides motion sensation, moves at a fixed rate but increase in size as they appear to move closer
3	Incremental Pitch Lines	Provides pitch angle in 5 degree increments
12	Reference Marker	Fixed at zero degrees pitch
14	Horizon Line	Provides ground and sky demarcation
19	Sky Shading	Provide sky reference (light shade)

Additional versatility is provided in that all control signals, random disturbances and timing pulses lend themselves to feedback to the digital computer for storage in real time and later use in some statistical analysis program. An example of this would be for the time of disturbance, amplitude of disturbance, time for pilot to correct for the disturbances, and the error of correction to be correlated with the EEG signal and amount of biofeedback.

C. BIOFEEDBACK SUBSYSTEM

This system is relatively simple, but it approaches all the requirements of a biofeedback system. Outputs from the digital computer via the D/A converter occur every 1/4 second with higher rates available with different programming. These outputs are used to drive one or more lamp control circuits which in turn drives background illumination lamps to provide continuous feedback without disturbing the operator at his task. In addition, the output of the D/A converter has the capability of driving quite a few of the symbols generated by the VDIG.

IV. FUNCTIONAL DESCRIPTION OF TASKING SUBSYSTEM

A. VERTICAL DISPLAY INDICATOR GROUP

The VDIG consists of two major units. They are, (1) a display generator or converter that creates the symbols which form the video signal and (2) a display indicator which displays the video signal on two displays, the vertical and head-up. As stated previously, the head-up is an optical projection on a pilot's field of view. Since there was no external environment on which to superimpose this display, its function and symbology was reserved as a possible means of feedback and will not be discussed in this section; however, its theory of operation is identical to that of the direct view indicator.

The direct view indicator provides a display with an image area of 5.2 inches in the vertical direction and 7 inches in the horizontal direction. Its vertical scale factor is 12 degrees per inch and the horizontal scale factor is 10.4 degrees per inch. These scale factors and dimensions result in a display of 60 degrees in the vertical direction and 75 degrees in the horizontal direction. The video displayed is a standard television 525 line, interlaced, 60 frames per second raster. The DVI contains its own raster control and generator circuits such as vertical deflection, video amplifier and roll servo. This roll servo is necessary to rotate the deflection yoke assembly in order to represent

the CRT picture earth stabilized in an aircraft. The DVI receives its video signal from the display generator.

The video signal supplied by the converter can be internally generated or from an external source. When internally generated signals are desirable, as in this pilot tasking system, the majority of their positions on the face of the CRT is determined by peripheal aircraft signals through Interface Adapter Units (IAU), [Fig. 4]. These IAU's then parallel feed a multiplexer and A/D converter where the positioning signal is converted to a 10-bit binary word. This 10-bit binary word is stored in a storage register and at the proper time is set into a preset counter. The preset counters with logic decode circuits assemble the positioning information with the proper symbol waveform. These symbol waveforms are then combined in the video mixer to form the video signal.

Each of those symbols chosen (because of their consistency with a pilot's see-thru vision) and represented in Fig. 3, are generated in this manner. As a more detailed example, take the Angle of Attack symbol. Its horizontal position is fixed on the CRT, but its vertical position is variable depending upon the pilot's input. To the pilot this symbol represents his desired flight angle with respect to the horizon. This is input to the system by a potentiometer located on the command air data computer. Its signal range is from -5 to +5 volts D.C. with -5 volts indicating a +25 degree Angle of Attack. In a direction sense, an Angle of Attack input signal going

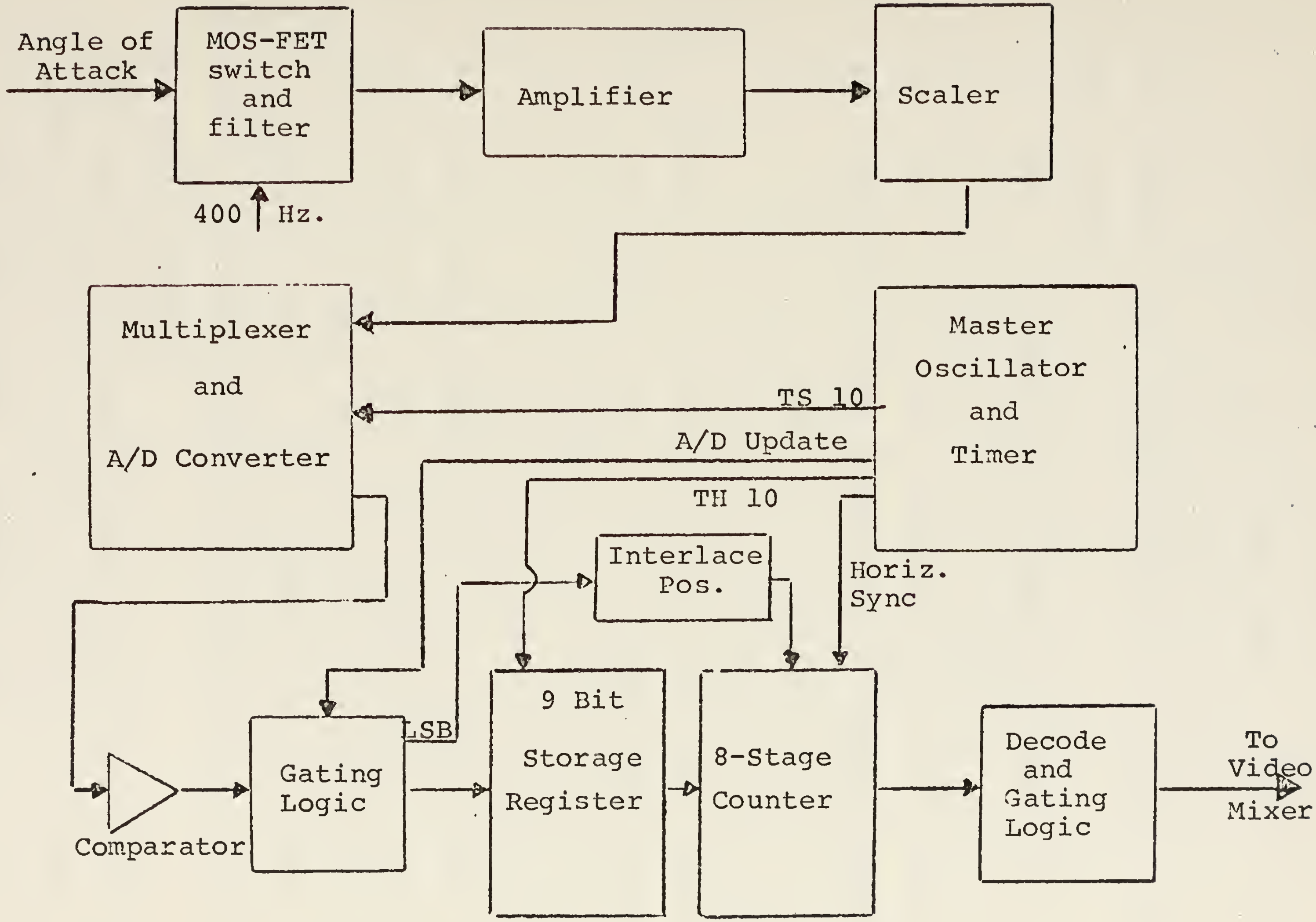


Figure 4. Angle of Attack signal flow.

toward +25 degree causes downward movement of the symbol and the pilot must increase his pitch angle to bring this symbol back to the vertical center of the screen. The following paragraphs provide a typical example for generating the Angle of Attack symbol with a block diagram of the signal flow provided in Fig. 4.

This signal is sampled in the Angle of Attack IAU with a MOS-FET switch pulsed by a 400 Hz reference signal, amplified and sent to the common multiplexer and A/D converter. Here the proper IAU input is selected by sample time (TS) signals, in this case TS-10, and converted to a 10-bit binary word. This 10-bit binary word is then sent to the proper symbol generator by the use of holding time (TH) signals generated by the master clock. In this example TH-10 gates bits 1-9 to a 9-bit storage register in the Angle of Attack Symbol generator. The least significant bit, bit 0, is used in an interlace positioning circuit. At each vertical sync pulse the contents of this 9-bit storage register are made available to an 8 stage vertical counter. Here again, the least significant bit is used in interlace positioning. Each horizontal sync pulse gates the 8 stage counter to the decoding and gating circuits.

The operation of these decoding and gating circuits is best understood by the use of boolean algebra expressions and the symbol wave-forms. Looking at Fig. 5, we see that the Angle of Attack symbol is formed by the combination of four discrete signals. The boolean expression is:

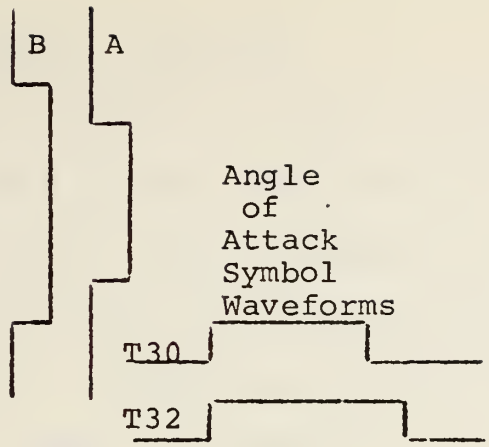
$$\text{Angle of Attack} = \overline{(A \cdot T32)} \cdot (B \cdot T30)$$

Since the horizontal position never changes we can use timing pulses for this positioning; but since the vertical position is changeable, it is necessary to move signals A and B in relation to the vertical sync pulse. This is accomplished by the decode circuit which consists of a group of NAND Gates. This Angle of Attack waveform is then sent to the video mixer where it is superimposed with the other symbols to form the video signal.

This same type of logic lends itself to the presentation of other types of displays. For instance, if it was desired to present the letter A (Fig. 6) to a subject, its boolean expression could be:

$$A = \overline{(\overline{E} + \overline{C}) \cdot (\overline{B} + \overline{D})}.$$

which could be moved vertically on the screen by changing the relationship of E and B with the vertical sync pulse and moved horizontally by changing C and D with respect to the horizontal sync pulse. This and other types of geometric symbols can be presented by the use of external logic circuits, the internal vertical and horizontal sync pulse and the external video mode.



Angle of Attack Symbol = $\overline{A(T32)} \cdot B(T30)$

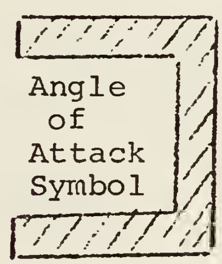


Figure 5. Generation of Angle of Attack symbol.

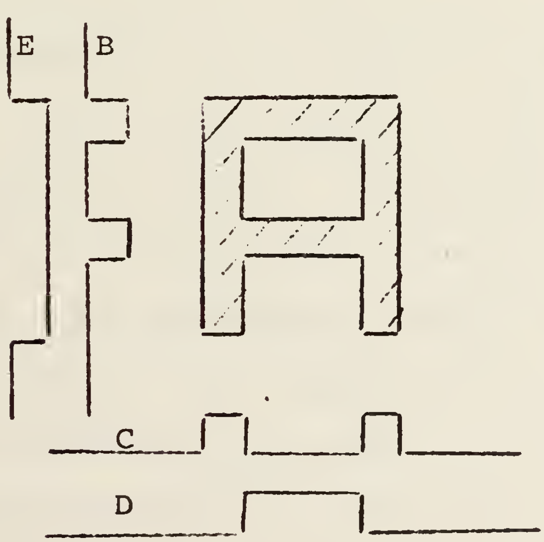


Figure 6. Generation of the letter A.

B. ANALOG AIRCRAFT SIMULATOR

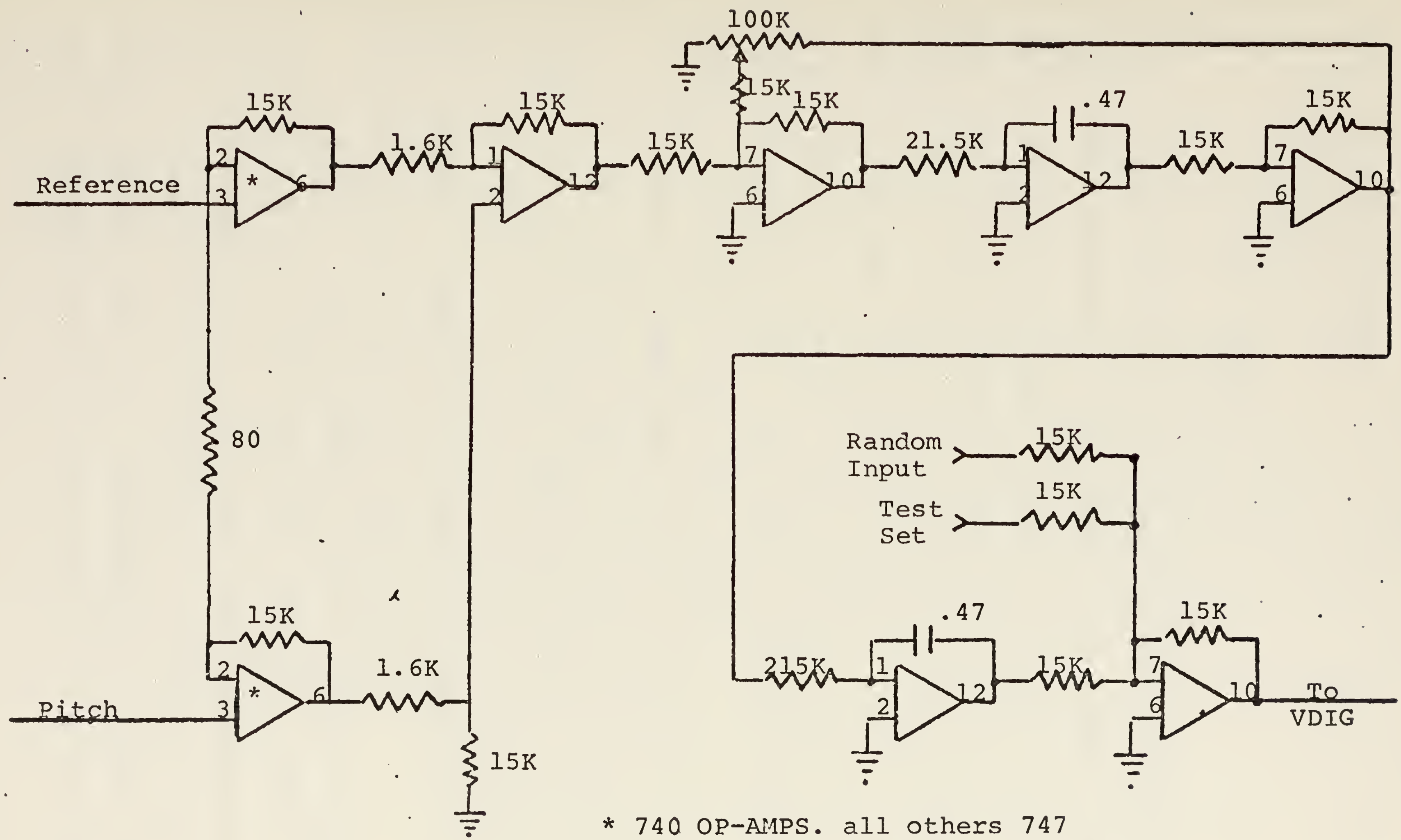
An aircraft simulator between the subject and task is necessary to make it more realistic and at the same time require more skill. With the chosen display symbols of Fig. 3, this realism could be achieved entirely through pitch and roll simulation. In addition, the exclusion of yaw and air speed simplify input requirements and avoid overcomplication of the aircraft equations of motion without serious effects on skill requirements.

The longitudinal or pitch circuit of Fig. 7 is an approximation of an F4-type aircraft flying at .9 Mach at sea level. With these assumptions its equation of motion becomes a second-order system with the Laplace transfer function:

$$H(s) = \frac{11600}{s\,(s + 2.6)}$$

Its output is considered to be the pitch angle affected by the dynamic short period mode. In the short period approximation, the airspeed remains constant, and therefore an elevator input results only in a change in the pitch angle. The magnitude of this change depends on the length of time the elevator input is actuated. In addition, the change in pitch will remain in effect (until removed) due to the lack of an airspeed or altitude change with any input.

The output stage of this simulator circuit was necessary to give proper interface to the VDIG. In addition, it adds the pitch random disturbances to the pilot desired position. The other input at this stage is a pitch trim from the V/HUD test set.



* 740 OP-AMPS. all others 747

Figure 7. Pitch analog simulator circuit.

The directional or roll analog circuit of Fig. 8 is a modified approximation, first-order system with Laplace transfer function:

$$H(s) = \frac{200}{s + .7} ,$$

of a stable aircraft. In a conventionally controlled aircraft, the pilot commands roll rate directly, but Ref. 12 implies pilots prefer an aircraft simulator to have a system where aileron control commands bank instead of roll rate. This system is one in which the pilot has to hold a steady stick force to maintain a steady bank angle. In this simulator, with stick force removed, the bank angle slowly returns to its original position. Here again, the final stage adds the random disturbance to the roll signal.

As previously mentioned, the VDIG utilizes a roll servo to turn the deflection yoke of the vertical display CRT in order to present an earth stabilized horizon. An alternative to this problem is to tilt the display electronically; but this method is unsatisfactory in that it presents a discontinuous horizon much like stair steps.

In Kaiser's servo system, a 400 Hz syncro is utilized as the input device to the roll servo loop, the output of the aircraft simulator is a D.C. level corresponding to angle of bank; therefore, it was necessary to provide an interface network between the two. The standard D.C. servo system block diagrammed in Fig. 9 was used to accomplish this purpose.

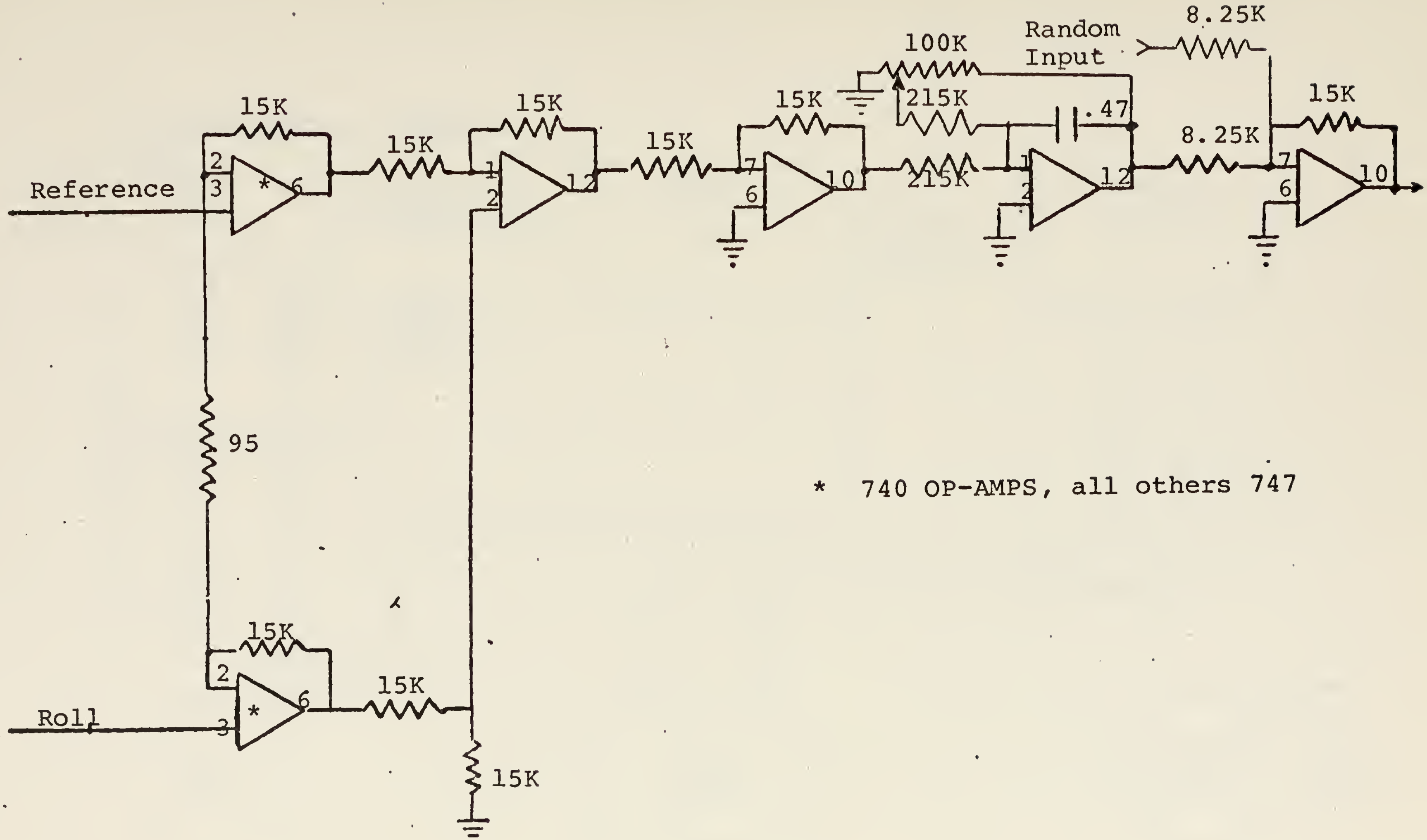


Figure 8. Roll analog simulator circuit.

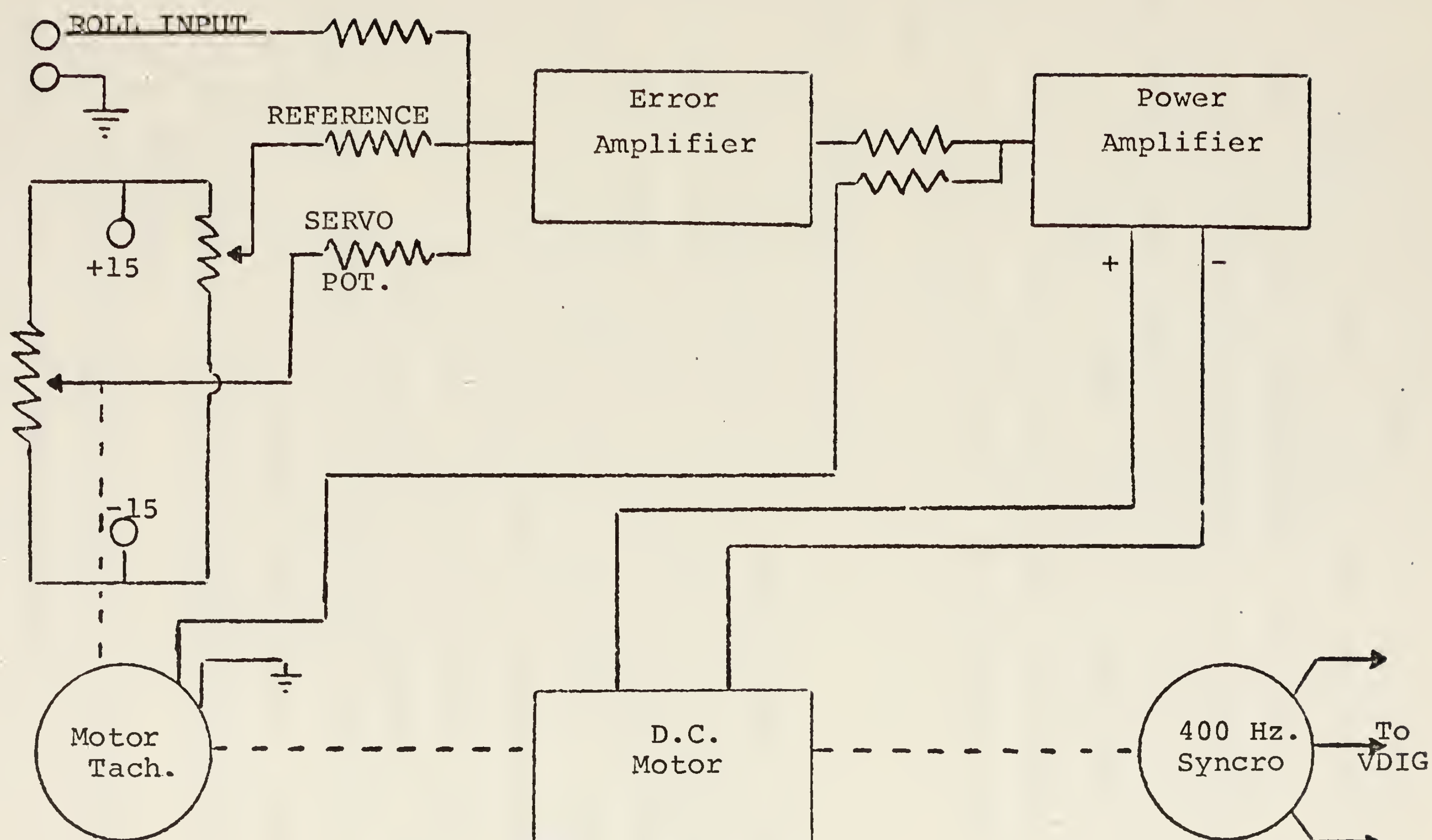


Figure 9. D.C. Servo system, block diagram

C. SIDE-ARM FORCE STICK

The side-arm force stick has four SR-4 strain gages, type FAB-25-12513, attached to the pitch and roll flexures as shown in Fig. 10. These strain gages, each 120.0 $\pm$ .2 ohms, were used as the variable resistances in a bridge-like arrangement that was energized with six volts by a well regulated power supply. This circuit is diagrammed in Fig. 11. The fixed 240 ohm resistor provides the reference voltage while the variable resistor in the pitch and roll legs are balance adjustments.

D. RANDOM DISTURBANCE GENERATOR

The relationship of the basic component parts of the pseudo-random disturbance generator are block diagrammed in Fig. 12. The premise of this system is that the properties of a feedback binary shift register with modulo 2 addition of selected cells as its input presents a pseudo-random binary sequence as its output and that sequence repeats itself every $2^n - 1$ bits, where n is the number of cells. To ensure that the disturbances presented to any one subject for a particular run did not repeat themselves, a value of 32 was selected for n, for which a sequence repeats itself every 4.3×10^9 bits.

In this circuit, diagrammed in Fig. 13, four 74199, 8-stage shift registers were used, with the final two bits, or cells, fed to a 7486 exclusive OR gate. This output was fed to the 32nd bit or input of the shift register. The 21st bit was

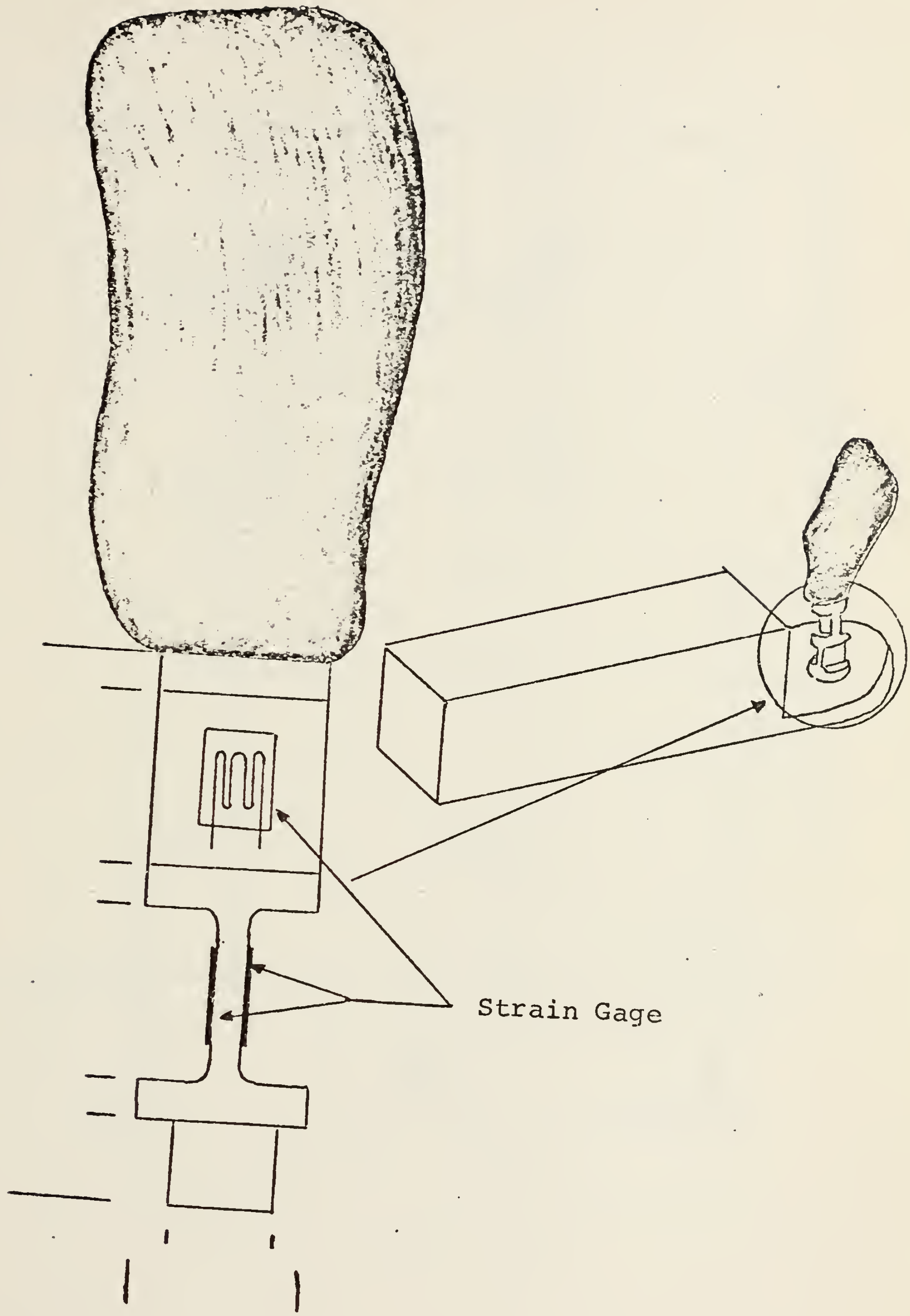


Figure 10. Side-arm Force Stick Strain Gage Placement.

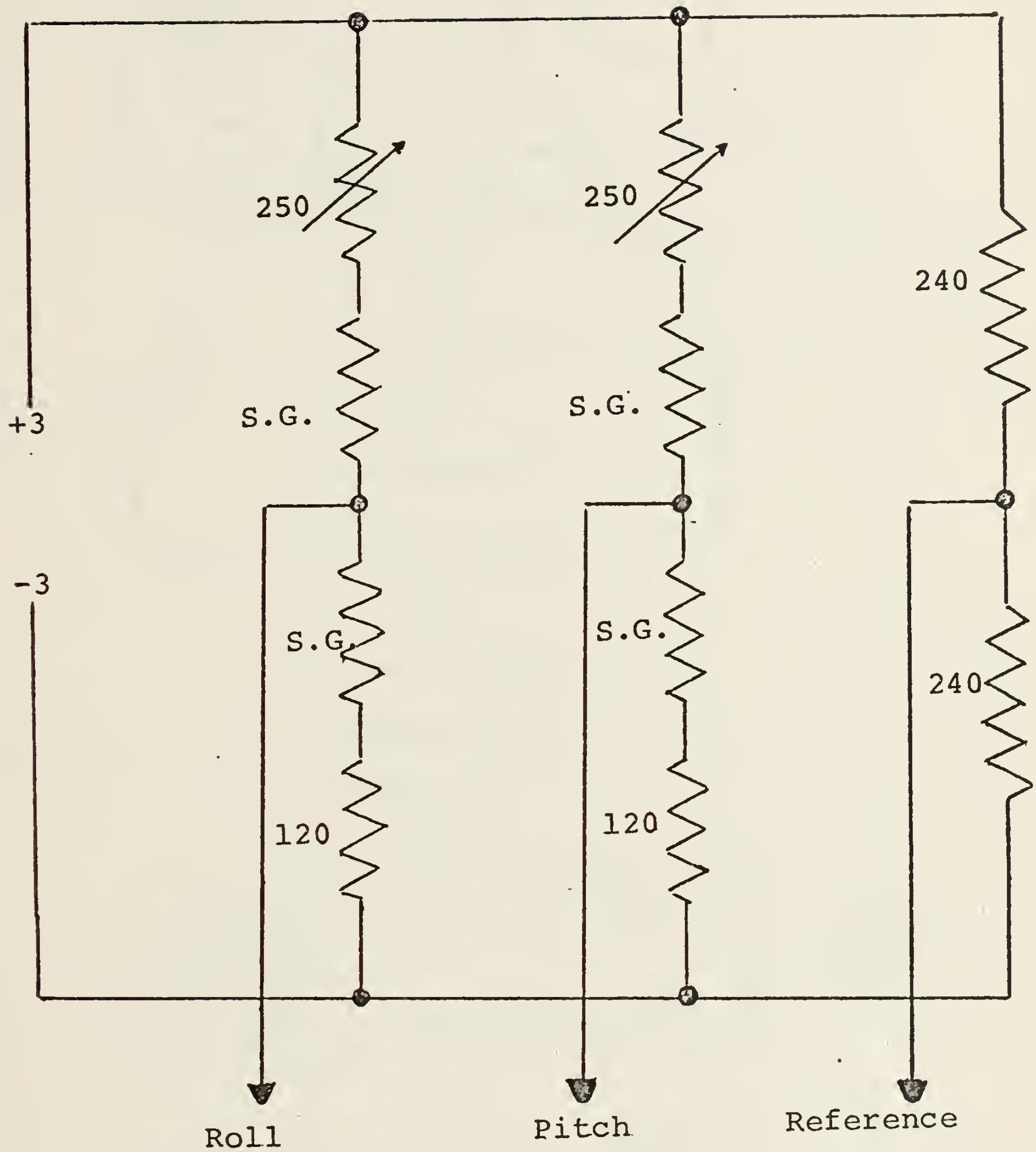


Figure 11. Strain Gage Bridge Circuit.

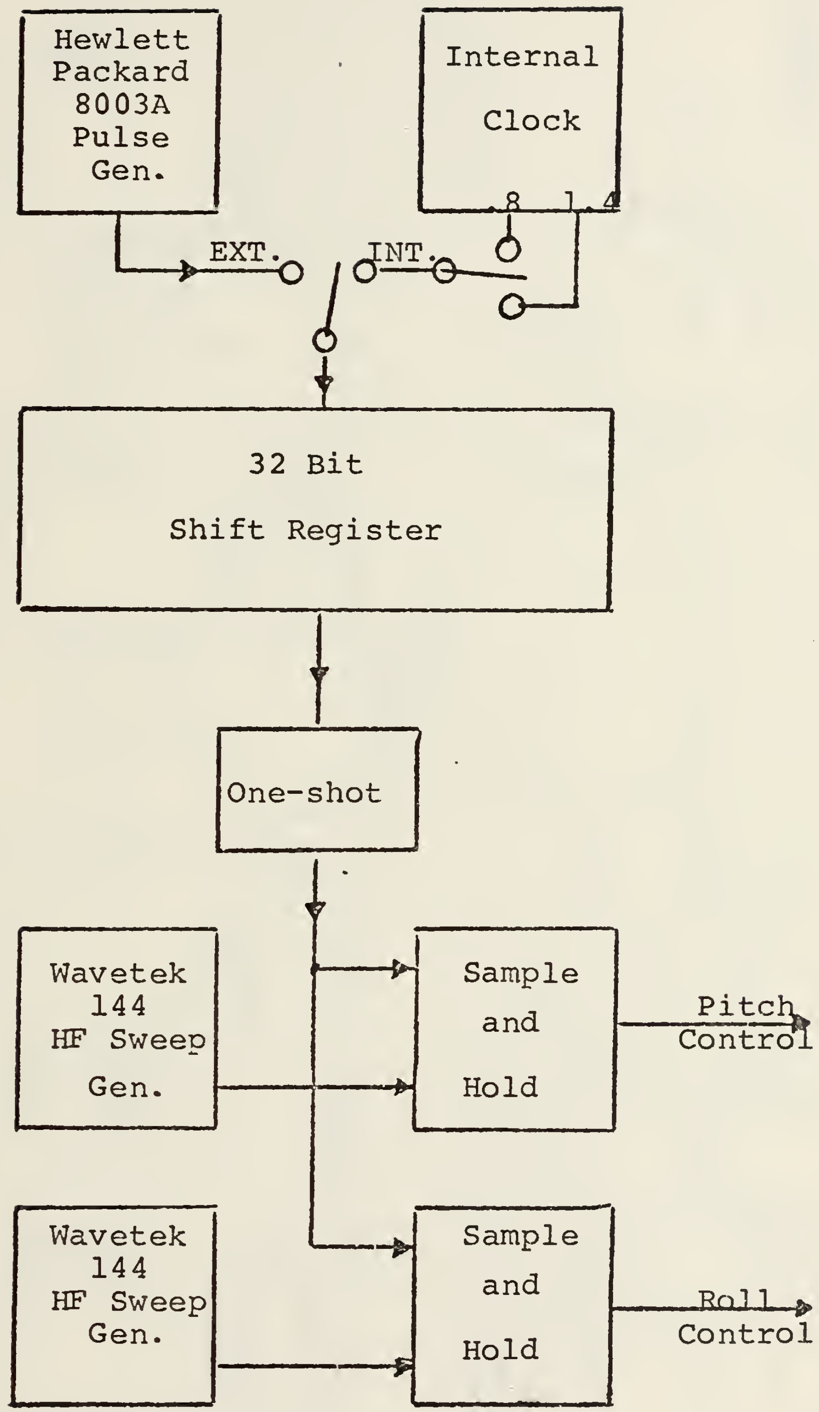


Figure 12. Random Disturbance Functional Block Diagram

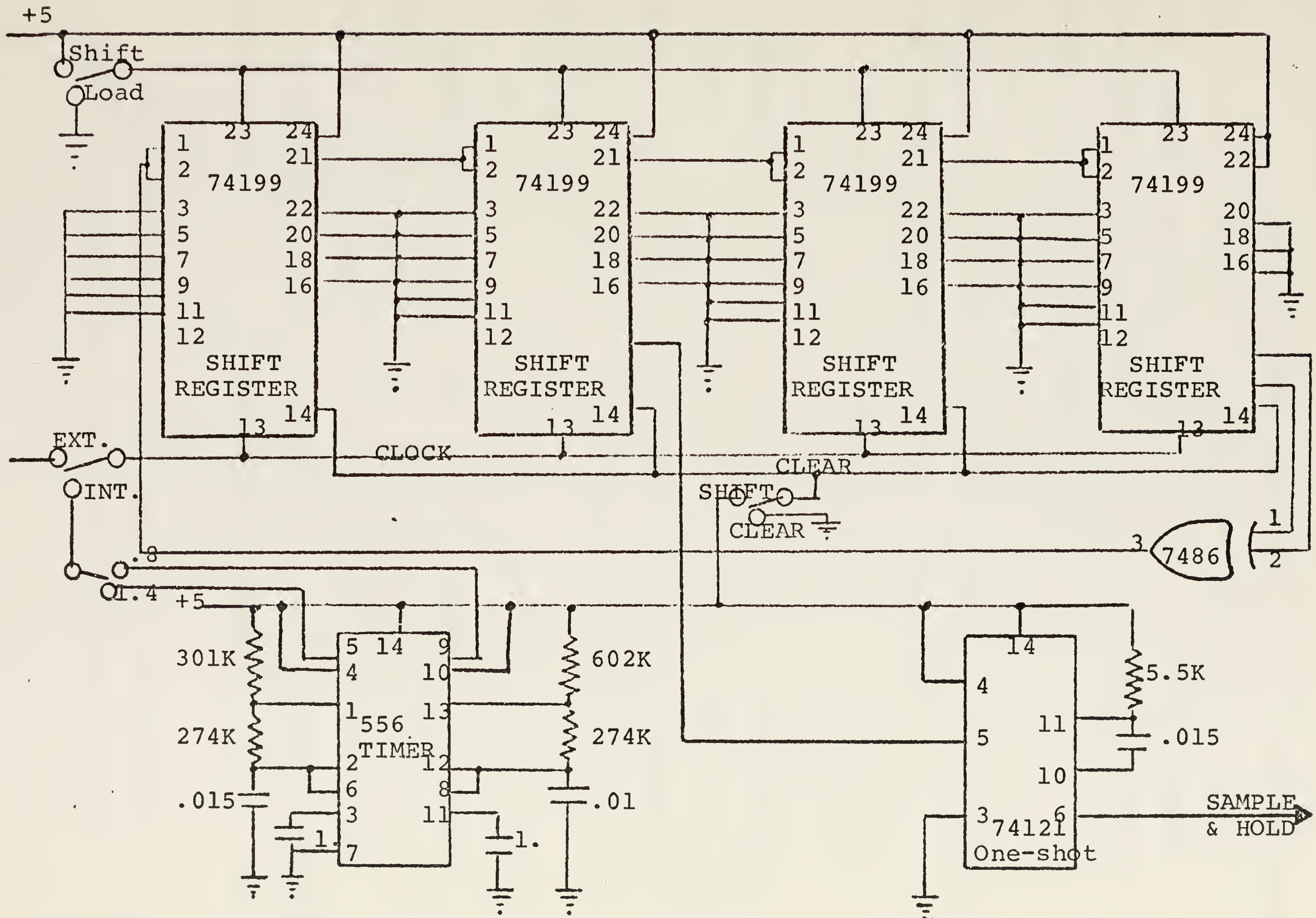


Figure 13. Random Pulse Gen. Schmatic Diagram.

arbitrarily chosen as the output bit to a 74121 one-shot multivibrator.

To control the rate of random disturbance, two internally generated clock pulses were manufactured using a Type 556 dual timer containing dual flip flops. With the circuit parameters shown in Fig. 13, these clock pulses occurred at a rate of .8 Hz and 1.4 Hertz, respectively. These rates proved to be too slow for seasoned fliers, so an external Hewlett-Packard pulse generator was added. This is normally run at 7 Hz to simulate "choppy, rough weather".

The output of the one-shot multivibrator was applied to two identical sample-and-hold networks of which one is diagrammed in Fig. 14. In this circuit, the instantaneous value of the input signal is sampled at the time of the one-shot output and held at the output until the occurrence of the next strobe pulse. This output is added to the pitch and roll simulator signals.

The operation of the circuit (Fig. 14) is quite simple: a strobe pulse at the input of IC2 turns on the junction FET Q1. This completes the feedback loop of IC1 (IC1, Q1 and Q2) and forces the .0047 μf capacitor to charge to a voltage equal to the input voltage. At the end of the strobe pulse, the loop is broken, and this voltage is held by the capacitor until the next strobe pulse.

Two Wavetek function generators supply the input signals to the pitch and roll sample-and-hold networks.

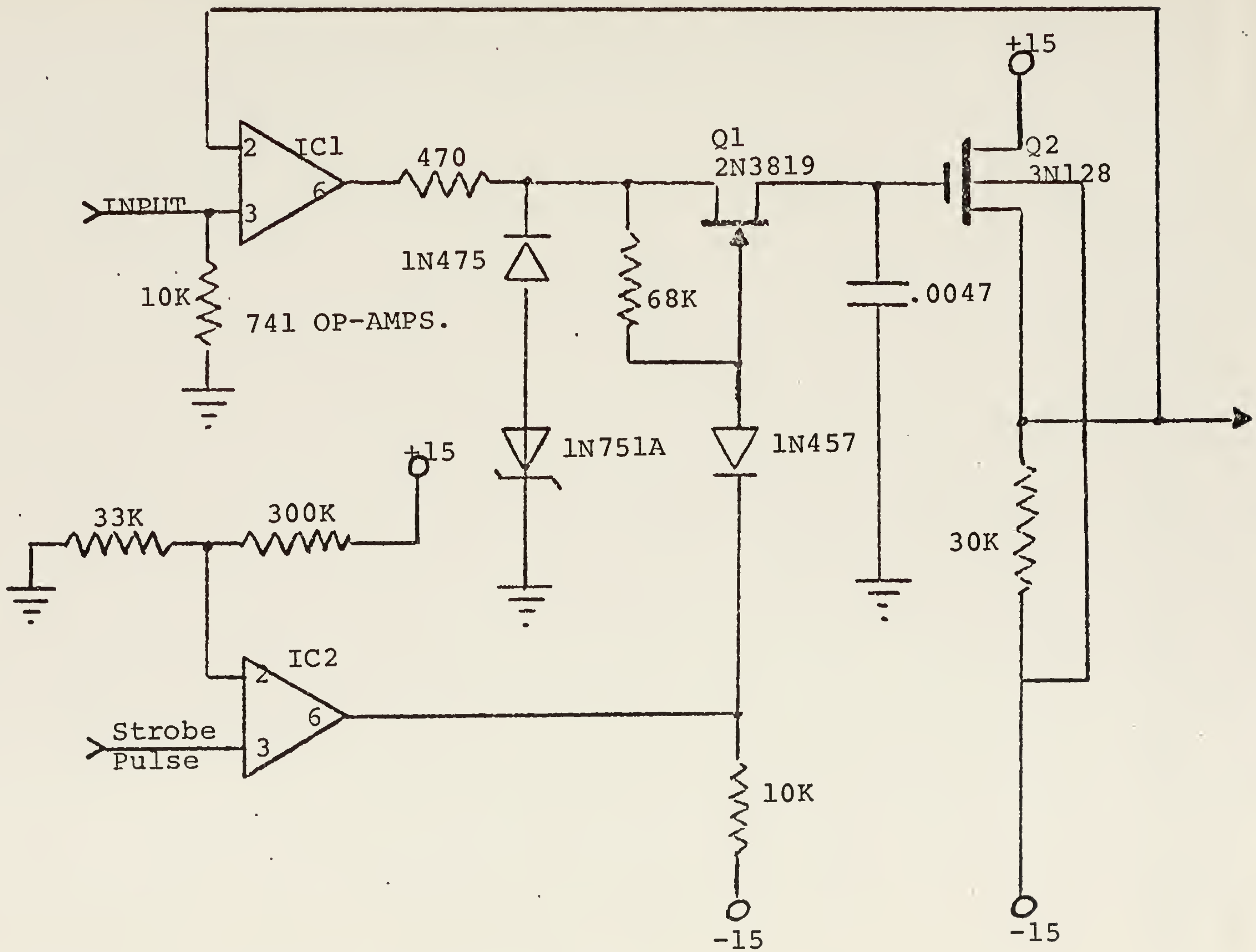


Figure 14. Sample and Hold Network

They are normally operated in a triangular wave mode, to take advantage of the uniform distribution property, at a frequency of 7 Hz for pitch and 13 Hz for roll. These particular frequencies were chosen to ensure no exact phase relationship existed between the two.

V. RESULTS AND CONCLUSIONS

In a worthwhile study and analysis program of the human EEG during mental activity, the subject must be tasked. An effective means of presenting this task is vital to ensure that he is interested, kept occupied and challenged. Some means for obtaining the time and quantitative nature of the subject's response to that task must be provided.

Basic principles? Yes; but how much time, energy and financial assistance has been wasted by paid subjects not caring or by a willing subject whose mind wanders or is distracted from his task by ineffective or faulty presentation. How many worthless stacks of data has been collected on subjects who were able to perform, rest and then perform, while the research team thought he was just performing? All these points and questions must be considered each time a project is undertaken and should be considered during each session.

The simulated flight tasking system described meets all of the requirements. Not only is the system capable of offering a variety of task to the pilot, via multi-display modes, but its external video mode is available for tasks as imaginative or creative as one would desire. The simulated flight mode need not be used for pilots alone, for the novice is intrigued at his abilities and fascination by the illusion of piloting an actual aircraft. In one respect a

non-pilot is more desirable for basic research, in that it takes more concentration on his part in order to accomplish a much simpler task.

To ensure continuing interest for pilots and non-pilots alike, the aircraft simulator is programmable for a variety of aircraft types. To maintain the subject occupied and challenged with the realization of an achievable goal, the rate and amplitude of random disturbances is controllable. To ensure that these conditions are met and to inform the group as to what the subject is doing, all input signals as well as subject's response are available as inputs to analog recorders or digital computers for correlation and other statistical analysis techniques.

Even though this system is capable of performing in a realistic manner, it has capabilities of future expansion. The next improvement to the system should be the addition of heading information, altitude control and speed inputs. These first two are realizable with outputs from the existing circuitry. The last could be achieved with modifications to the equations of motion and an input device such as a non-linear potentiometer. These additions would increase the realizism and difficulty of the task.

Limited experimental results are encouraging in that, as the task increases in complexity, the correlation between EEG signals of cortical activity picked up by two closely spaced electrodes has a step increase at the onset of the new task. It should also be pointed out that the correlation

depends upon frequency bands utilized for analysing the EEG. The addition of biofeedback has facilitated an increase in the degree of correlation for the same subject and task. We are led to the conclusion that there is a preferred frequency to mental processing [Ref. 13] and the degree of mental activity is enchanced by biofeedback.

The results of these experiments and others are good so far and have opened a whole new range of exploration into brain EEG properties. Future areas of thesis research could be: (1) mapping for areas of greater correlation, (2) narrowing of frequency range of correlation, and (3) increasing the capabilities of the tasking system. These future studies and their results could lead to greatly improved methods of biofeedback. These in turn could be useful in (1) giving a pilot a quantitative measure of his alertness and attention, (2) as an important training aid and (3) as the basis of a new means of selecting trainees.

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